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APPLICATION FOR U.S. LETTERS PATENT

Title:

USE OF AN IMAGE REJECT MIXER IN
A FORWARD DATA CHANNEL TUNER

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TITLE OF INVENTION

USE OF AN IMAGE REJECT MIXER IN A FORWARD DATA CHANNEL TUNER

TECHNICAL FIELD OF THE INVENTION

[0001] The invention relates generally to communication signal processing and, more particularly, to frequency conversion of an out of band signal using an image reject mixer.

BACKGROUND OF THE INVENTION

[0002] In particular radio frequency (RF) applications it may be desirable to utilize a signal which is relatively low in amplitude as compared to other signals present in a communication system and/or which is present in a signal channel having other signals or noise energy very near thereto. Providing signal processing, such as signal down-conversion common in signal tuner applications, is particularly challenging with respect to such signals.

[0003] The OPENCABLE specifications from Cable Television Laboratories, Inc., for example, provide for three major RF functions via a common signal path, wherein the signal levels associated with one or more of the functions are significantly attenuated with respect to other ones of the signals. Moreover, the OPENCABLE signal channels are established very near other signal channels and/or occurrences of noise energy. To further complicate operation according to OPENCABLE specifications, the specifications establish relatively stringent signal quality requirements.

[0004] Specifically, the three major functions provided by the OPENCABLE specifications include a forward application terminal (FAT), a forward data channel (FDC), and a reverse data channel (RDC). The forward application terminal provides downstream analog National Television System Committee (NTSC) signals and high speed digital 64/256 quadrature amplitude modulation (QAM) signals in 6 MHz channel spacings. The forward data channel provides downstream low speed digital quaternary phase-shift keying (QPSK) signals in 1.0, 1.5, or 2.0 MHz channel spacings. The reverse data channel provides upstream low speed digital QPSK signals. Collectively, the forward data channel and the reverse data channel are often referred to as out-of-band.

[0005] The forward data channel of the OPENCABLE specification is provided for transmission within the 70 MHz to 130 MHz frequency band, and may be down-converted to a particular frequency, such as 36 MHz, for use by a terminal device, such as a set-top box. The forward application terminal channels are provided for transmission within the 54 MHz to 864 MHz frequency band, inclusive of the 70 MHz to 130 MHz frequency band (i.e., the 70 MHz to 130 MHz frequency band may be mixed use). Signals of the forward data channel are typically as much as 22 dB lower in amplitude than signals of the forward application terminal channels. Yet the output signal to noise and distortion (SINAD), or carrier to noise and interference ($C / (N + I)$), for the forward data channel is 20 dBc. These specifications lead to difficult and demanding signal processing requirements.

[0006] Specifically, forward data channel processing circuitry operating according to the aforementioned OPENCABLE specifications must accept signals from 70 MHz up to 130 MHz and provide down-conversion thereof to result in a signal to noise and distortion ratio of at least 20 dBc. However, at typical down-conversion frequencies, such as the aforementioned 36 MHz, images of the accepted frequency band are very near the frequencies of the accepted bandwidth. For example, the image frequency of 70 MHz, when down-conversion to 36 MHz is implemented, is 142 MHz ($70 + (2 \cdot 36) = 142$). Accordingly, operation according to the specification requires down-conversion of frequencies as high as 130 MHz while needing to exclude images as low as 142 MHz.

[0007] Typical forward data channel processing circuitry which has been proposed includes a series of low pass filters provided in the signal path prior to a down-converter in order to reject noise energy including image frequencies, such as the aforementioned 142 MHz image frequency. For example, typical implementations utilize a down-converter having mixer oscillator circuitry outputting the down-converted signal as well as the image of the RF input. Therefore, to provide the desired signal quality at the output of such circuitry, it is necessary to filter out the image frequency entirely externally, such as by using discrete element capacitors and inductors in a discrete filter arrangement.

[0008] However, it is very difficult to build a sufficient low pass filter to adequately reject frequencies so closely spaced, such as with the 12 MHz separation between the high end pass frequency of 130 MHz and the 142 MHz image frequency. Specifically, in operation according to the OPENCABLE specification, required image rejection is set forth by the

equation: (FDC to FAT adjacent channel amplitude) + (required signal to noise and distortion ratio) + (sufficient margin to all for other sources of noise and distortion) which, in practice, may establish an image rejection requirement of approximately $22\text{ dB} + 20\text{ dB} + 10\text{ dB} = 52\text{ dB}$. The difficulty in implementing circuitry to achieve such image rejection arises due to both the large amount of image rejection required, and the close spacing between the desired and image frequencies.

[0009] Building a low pass filter network suitable for meeting the image rejection requirements above, particularly from discrete components available today at costs conducive to mass production of circuitry acceptable in the marketplace in applications such as cable television terminal devices and/or broadband communication devices, is difficult. Moreover, in order to facilitate mass production of such circuits, it is desirable to avoid requiring manual alignment or adjustment of circuit attributes, as is commonly required with discrete component implementations.

[0010] One prior art solution with respect to providing such filtering has been to utilize a surface acoustic wave (SAW) filter rather than the multiple discrete component filter stages discussed above. However, the use of SAW filters is itself not without disadvantages. For example, SAW filters provide fixed pass-bands and, therefore, are useful only in situations where an out-of-band signal to be utilized is of a fixed frequency. Moreover, SAW devices are not capable of integrated circuit implementation using current technology and, therefore, must be provided as a discrete circuit component.

[0011] Accordingly, a need exists in the art for systems and methods that provide high signal quality output frequency conversion of signals relatively low in amplitude as compared to other signals present in a communication system and/or which are present in a signal channel having other signals or noise energy very near thereto. A further need exists in the art for such systems and methods to be adapted for mass production and/or deployment with little or no manual alignment or adjustment thereof.

BRIEF SUMMARY OF THE INVENTION

[0012] The present invention is directed to a system and method which utilizes an image reject mixer in an out-of-band mixer application such as in a forward data channel tuner. For example, according to a preferred embodiment, an image reject mixer may be utilized to provide

a relatively high degree of image rejection with respect to an out-of-band signal, thereby relaxing the requirement for filtering in the signal path leading to the mixer circuitry. Accordingly, a preferred embodiment of the present invention provides an image reject mixer providing approximately 20-25 dB of image rejection in combination with a filter network providing approximately 27-32 dB of image rejection, for use with a forward data channel of a cable system protocol, such as that of the OPENCABLE specifications.

[0013] A technical advantage of the present invention is that frequency conversion of signals, having relatively low amplitude as compared to other signals present in a communication system, provides high signal quality output, such as carrier to noise and interference ratios of approximately 20 dB. Similarly, a technical advantage of the present invention is that frequency conversion of signals, having other signals or noise energy very near thereto, provides high signal quality output.

[0014] A further technical advantage of the present invention is that high signal quality output is provided from frequency conversion using circuitry which minimizes reliance upon discrete components and is adapted for mass production and/or deployment with little or no manual alignment or adjustment thereof.

[0015] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present invention.

BRIEF DESCRIPTION OF THE DRAWING

[0016] FIGURE 1A shows a prior art forward data channel frequency conversion circuit;

[0017] FIGURE 1B shows a typical embodiment of a low pass filter used in the frequency conversion circuit of FIGURE 1A;

[0018] FIGURE 2A shows a block diagram of a preferred embodiment forward data channel frequency conversion circuit of the present invention;

[0019] FIGURE 2B shows a schematic diagram of a preferred embodiment of the forward data channel frequency conversion circuit of FIGURE 2A; and

[0020] FIGURE 3 shows a block diagram of an image reject mixer utilized in a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Directing attention to FIGURE 1A, frequency conversion circuitry for use in converting a forward data channel provided according to the OPENCABLE specifications, as has typically been proposed, is shown generally as frequency conversion circuit 100. Specifically, FIGURE 1A shows a high level block diagram of frequency conversion circuitry, including low pass filter 101, fixed gain buffer amplifier 102, low pass filter 103, fixed gain buffer amplifier 104, low pass filter 105, adjustable gain amplifier 106, and mixer 107.

[0022] In operation according to the embodiment of FIGURE 1A, and as is typical in implementations for which frequency conversion circuit 100 would be deployed, an RF forward data channel signal in the frequency range of 70 MHz to 130 MHz would be provided at the port labeled RF for down-conversion to 36 MHz by frequency conversion circuitry 100 and output at an intermediate frequency (IF) at the port labeled IF. It should be appreciated that if a forward data channel signal at 70 MHz is selected for down-conversion to 36 MHz, the local oscillator frequency (provided to the port labeled LO) may be 106 MHz (i.e., $106 \text{ MHz} - 70 \text{ MHz} = 36 \text{ MHz}$). However, mixer 107 will provide output of signals in addition to that which is the difference between the local oscillator frequency and the signal of interest. For example, noise energy or other signal energy appearing at any frequencies provided to mixer 107 will be mixed with the local oscillator frequency to result in frequency converted signals of various

frequencies. Unfortunately, the frequencies of these other energy sources may appear at or near the frequency of the frequency converted signal of interest. For example, not only is the difference between 106 MHz and 70 MHz equal to 36 MHz, but the difference between 142 MHz and 106 MHz is also equal to 36 MHz.

[0023] The OPENCABLE specifications provide for forward data channel signaling in the frequency band from 70 MHz to 130 MHz and, therefore, mixer 107 is provided with at least this band of frequencies for down-conversion to a desired intermediate frequency (IF). However, in order to provide an output signal of a quality meeting the OPENCABLE specifications, it is necessary to substantially reject energy at 142 MHz and higher from the signal input of mixer 107. Accordingly, mixer 107 must be provided signals of up to 130 MHz while not being provided signals of 142 MHz.

[0024] It should be appreciated that it is typically not practical to provide a single filter with a frequency response sufficient to satisfactorily pass the high end frequencies of the OPENCABLE forward data channel pass band, without appreciable attenuation, and reject relatively close frequencies, such as the aforementioned 142 MHz signals having an image at the desired IF. Accordingly, a cascade filter approach is commonly proposed for use as shown in FIGURE 1A, wherein multiple low pass filters are provided in series in order to pass desired signals of the forward data channel, the frequency band from 70 MHz to 130 MHz, while rejecting energy in frequencies as close to the pass band as 142 MHz. Typically, in such a cascade arrangement, at least low pass filter 105 of FIGURE 1A provides a relatively complicated filter network in order to provide a precise cutoff frequency and/or a sharp frequency cutoff to thereby produce an IF output signal from mixer 107 meeting the desired signal quality requirements. A typical configuration of low pass filter 105 including a network of inductors and capacitors to provide a relatively precise cutoff frequency and/or sharp frequency cutoff are shown in FIGURE 1B.

[0025] However, implementing filters having precise cutoff frequencies and/or sharp frequency cutoff response, such as the LC network of FIGURE 1B, using components of a typical quality available for mass production often require manual tuning or other adjustment in order to achieve a desired level of performance. Accordingly, the labor costs of a mass produced frequency conversion circuit as shown in FIGURE 1A may be excessively high and/or the

reliability of such circuits may be unacceptably low for consumer electronics deployment, such as in cable television set-top boxes or cable modems.

[0026] Moreover, the number of discrete components utilized in providing the filters of the above described frequency conversion circuit typically requires significant space. For example, the relatively complex filter circuit provided by low pass filter 105 generally must utilize discrete components in order to achieve the desired precise cutoff frequencies and/or sharp frequency cutoff response. However, as can be seen by the filter network of FIGURE 1B, such a discrete component embodiment of the filter occupies an amount of space which is undesirable for many modern consumer electronic applications.

[0027] Directing attention to FIGURES 2A and 2B, frequency conversion circuitry of a preferred embodiment of the present invention, such as may be used in converting a forward data channel provided according to the OPENCABLE specification, is shown generally as frequency conversion circuit 200. Specifically, FIGURE 2A shows a high level block diagram of frequency conversion circuitry, including low pass filter 201, fixed gain buffer amplifier 202, low pass filter 203, adjustable gain amplifier 206, and image reject mixer 207. Also shown in FIGURE 2A for completeness are coupler 211, intermediate frequency band pass filter 212, and output buffer amplifier 213.

[0028] Coupler 211 is shown in FIGURE 2A for completeness, and is not directly utilized in the frequency conversion of signals. For example, a cable signal, including the aforementioned FAT channels and FDC, may be provided via a service provider's network to subscriber equipment, such as a set-top box or a cable modem, or other equipment utilizing FDC information. Coupler 211 may be provided within such equipment to pass the cable signal to components in the subsequent signal path while providing the cable signal to the frequency converter of the present invention. For example, coupler 211 may be a directional coupler having approximately 1 dB of loss in the through path, to thereby pass the FAT channel to a television tuner, and having approximately 10 dB of loss in the coupled leg thereof, to thereby feed the forward data channel to the frequency converter of the present invention.

[0029] As with coupler 211 discussed above, intermediate frequency band pass filter 212 and output buffer amplifier 213 are shown for completeness and are not directly utilized in the frequency conversion of signals. Intermediate frequency band pass filter 212 and output buffer

amplifier 213 may be provided as an output stage of the frequency conversion circuit in order to provide blocking of undesired frequencies and buffering of the output signal.

[0030] In operation according to the embodiment of FIGURE 2A, an RF signal including a out-of-band signal, such as a forward data channel signal in the frequency range of 70 MHz to 130 MHz of the OPENCABLE specification, may be provided at the port labeled RF. This signal is coupled to the frequency conversion circuit of the preferred embodiment for down-conversion, such as to intermediate frequencies in the range of 36-45 MHz, and output at an intermediate frequency (IF) at the port labeled IF. Specifically, the coupled signal is filtered by low pass filter 201, buffered by fixed gain buffer amplifier 202, filtered again by low pass filter 203, and amplitude adjusted by adjustable gain amplifier 206 before being provided to image reject mixer 207 of the preferred embodiment.

[0031] In contrast to the prior art circuit discussed above with respect to FIGURES 1A and 1B, in providing an output signal of a quality meeting the OPENCABLE specifications, the preferred embodiment of FIGURE 2A utilizes only relatively simple filter networks. Directing attention to FIGURE 2B, further detail with respect to a preferred embodiment implementation of the functional blocks of FIGURE 2A is shown. In FIGURE 2B each of low pass filters 201 and 203 are shown to include a relatively simple arrangement of discrete inductors and capacitors to thereby provide simple LC filters. Accordingly, the most simple filter network of the preferred embodiment, low pass filter 201, may provide a relatively coarse frequency cutoff point, such as passing signals at 130 MHz and rejecting signals at frequencies of approximately 150 MHz and greater where it is ultimately desired to reject signals at 142 MHz and greater. The more complex filter network of the preferred embodiment, low pass filter 203, although still providing a relatively simple filter circuit, may provide a more precise frequency cutoff point although not providing a sharp frequency cutoff response, such as to pass signals at 130 MHz and appreciably attenuate signals at 142 MHz and greater.

[0032] It should be appreciated that implementation of the relatively simple filters described above may be accomplished using readily available discrete components, such as inductors and capacitors commercially available having 10% tolerances, without the need for manual tuning or other adjustment while meeting the requirements for use in the preferred embodiment. Likewise, alternative embodiments of the present invention leverage the less demanding requirements of the above discussed preferred embodiment filters utilizing integrated

circuit filter networks, such as where all or some of the above filter components are disposed on a common monolithic silicon substrate.

[0033] Image reject mixer 207 of the preferred embodiment is utilized in combination with the above described relatively simple filters in providing an output signal of the desired quality according to the present invention. Specifically, because image reject mixer 207 is itself able to reject at least a portion of the undesired signal energy, it is not necessary according to the preferred embodiment to reject all such undesired signal energy, such as that present at 142 MHz, prior to frequency conversion by image reject mixer 207.

[0034] It should be appreciated that preferred embodiment image reject mixers of the present invention are adapted to provide mixing with respect to a plurality of channels, such as for selection of forward data channels of a plurality of forward data channels in the frequency range of 70 MHz to 130 MHz. Accordingly, in such embodiments the use of a single SAW filter, in addition to not facilitating integration of the mixer and filtering circuitry, would generally not provide desirable signal processing characteristics. However, the low pass filters of the illustrated embodiment are preferably adapted to pass all such signals of interest while providing desired levels of attenuation with respect to signal energy at undesired image frequencies according to the present invention. Of course, embodiments of the present invention may utilize a tracking filter or filters, if desired.

[0035] Directing attention to FIGURE 3, an image reject mixer, such as may be implemented as image reject mixer 207 of the preferred embodiment, is shown. As shown in FIGURE 3, the signal provided to the image reject mixer may include both a desired RF component and an undesired image (IM) component. The input signal is split for mixing with a local oscillator (LO) frequency and a phase delayed LO (90° phase delayed in the illustrated embodiment), thereby providing a first intermediate frequency signal (IF₁) and a second intermediate frequency signal (IF₂). In the illustrated embodiment IF₁ comprises RF – LO at 0° and LO – IM at 180°. Similarly, IF₂ comprises RF – LO at 0° and LO – IM at 0°. The intermediate frequency signals are combined for output from the image reject mixer thereby canceling the LO – IM component of each of the intermediate frequency signals.

[0036] It should be appreciated that image reject mixer 207 of the preferred embodiment may be implemented utilizing integrated circuit technology, such as by disposing the

components shown in FIGURE 3 on a common monolithic silicon substrate. Moreover, amplifier circuits, such as fixed gain buffer amplifier 202, adjustable gain amplifier 206, and/or output buffer amplifier 213, may be implemented utilizing integrated circuit technology. Accordingly, a preferred embodiment of the present invention disposes each of fixed gain buffer amplifier 202, adjustable gain amplifier 206, image reject mixer 207, and output buffer amplifier 213 on a common monolithic substrate, represented by 250 of FIGURE 2A, to provide a highly integrated circuit embodiment frequency conversion circuit. Additionally, as mentioned above, low pass filters 201 and 203 may be implemented utilizing integrated circuit technology and, therefore, an alternative embodiment of the present invention may provide any or all of low pass filter 201, fixed gain buffer amplifier 202, low pass filter 203, adjustable gain amplifier 206, image reject mixer 207, and output buffer amplifier 213 on a common monolithic substrate.

[0037] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or late to be developed that perform substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.